The Hopfion Universe: A 4D Topological Encoding of Spacetime, Matter, and Quantum Fields via Conserved Hopf Charge

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1 Abstract

We propose that the fundamental structure of spacetime is a 4-dimensional Hopfion—a topologically non-trivial soliton in 4D Euclidean space whose Hopf invariant is conserved and non-zero. All matter, forces, and the arrow of time emerge from the self-similar nesting of Hopf fibration structures across scales. Quarks are the irreducible topological data units (the "forward hash") that encode this charge and cannot be isolated or brought to rest without infinite energy. Gravity emerges as the residual "bleed" of electromagnetic energy not fully incorporated into the topological weaves of the fibrations, explaining its relative weakness. Entropy and the second law arise from the irreversibility of information hashing into these topological structures during fibration nesting and rescaling. This model unifies gravity, quantum mechanics, and the cosmological constant in a single topological invariant, predicts testable signatures at every scale, and is falsifiable by current and near-future experiments.

2 Core Postulate

The universe is a single, eternal 4D Hopfion (or a fractal hierarchy of nested Hopfions). The total Hopf invariant $Q \in \mathbb{Z}$ is conserved and non-zero. All physical degrees of freedom are projections or fibrations of this 4D topological charge.

3 Key Predictions – Testable at Every Scale

Scale	Prediction
Planck / Quantum Gravity	Vacuum energy density $\Lambda \propto Q/(4\pi^2\ell_P^4)$ where Q is the global Hopf charge
QCD / Particle Physics	Free quarks impossible; no zero-velocity color-charged state exists
Atomic / Condensed Matter	Persistent zero-point motion in all confined systems (no true ground state)
Astrophysics / Cosmology	CMB power spectrum shows self-similar (fractal-like) correlations across decades of scale
Gravitational Waves	Stochastic GW background from primordial Hopfion decay (cosmic strings, domain walls)
Black Hole Physics	Hawking radiation carries topological correlations (non-thermal component)
High-Energy Colliders	No new particles beyond Standard Model + gravity; all new physics is topological

4 Falsification Criteria

The model is falsified if any of the following are observed:

- A free, color-singlet quark at finite rest mass and zero velocity

- A true, motionless QCD vacuum ground state with zero residual energy
- A cosmological constant that is not tied to a quantized topological charge
- Absence of self-similar fractal signatures in the CMB at high resolution
- Detection of a particle or field that cannot be interpreted as a projection of 4D Hopf fibration

5 Mathematical Framework (Outline for Paper)

1. 4D Hopfion as Fundamental Soliton
   - Define the 4D Euclidean action with a Skyrme-like term:

     $$S = \int d^4x \, (\partial_\mu U)^2 + \kappa (U^\dagger \partial_\mu U)^2$$

     where U is an SU(2)-valued field (or higher group for QCD).
   - Hopf invariant $Q = (1/24\pi^2) \int \mathrm{Tr}(U^{-1}\partial_i U [U^{-1}\partial_j U, U^{-1}\partial_k U]) \epsilon^{ijkl} \, d^4x$
2. Emergence of 3D Space and Time
   - Time emerges as the Hopf fiber S^1 direction; 3D space is the base S^2/S^3.
   - Expansion/contraction of the universe is a rescaling of the Hopfion radius.
3. Quarks as Topological Data
   - Quarks are the endpoints of color-flux tubes (Hopf links).
   - Confinement is topological: separating quarks increases linking number $\rightarrow$ infinite energy.
4. Cosmological Constant as Topological Energy
   - $\Lambda = (8\pi G/c^4) \times (Q/R^4)$ where R is the current Hopfion scale radius.
5. Emergence of Gravity
   - Gravity is not a fundamental force but emerges as the residual "bleed" of electromagnetic energy that is not fully incorporated into the topological weaves (fibrations) of the Hopfion. In the solitonic field ontology inspired by Korobochka [2], quantum mechanics arises as the low-energy limit of nonlinear electromagnetism under Lorentz invariance. Here, the 4D action embeds electromagnetic-like terms, but during weave formation, most energy is channeled into stabilizing the conserved topological charge Q, leaving a weak, long-range remnant that manifests as gravity.
   - Formally, split the energy density: $\rho_{\text{total}} = \rho_{\text{weave}} + \rho_{\text{bleed}}$, where $\rho_{\text{weave}} \propto Q/R^4$ is topologically confined, and ρ_{bleed} induces spacetime curvature via Einstein's equations $G_{\mu\nu} = (8\pi G/c^4) T_{\mu\nu}$, with $T_{\mu\nu}$ sourced from the leaked electromagnetic stress-energy tensor outside the weaves. This explains gravity's weakness relative to electromagnetism, as $\rho_{\text{bleed}} \ll \rho_{\text{weave}}$.
   - In high-energy regimes like quark-gluon plasma, weave formation is rapid, minimizing bleed and rendering gravity negligible, consistent with particle physics observations.
6. Entropy and the Second Law
   - Thermodynamic entropy emerges from the irreversibility of information "hashing" into topological structures during the nesting and rescaling of Hopf fibrations. The second law (entropy increases in closed systems) follows from the topological protection of the Hopf invariant: Interactions between solitons (scattering or merging) generically increase the complexity of windings and linking numbers, which cannot be reversed without violating Q conservation.

- Entropy S is quantified as $S \approx k_B \log(W)$, where W is the number of micro-fibrations (windings) compatible with the macro-state defined by Q. During Hopfion rescaling (e.g., contraction phases), information from previous states is hashed into irreducible units like quarks, leading to irreversible dissipation. This is analogous to the non-zero residuals in simulations, ensuring persistent motion and preventing total reversal.
- In plasma states or soliton collisions (drawing from Korobochka's maximal Lagrangian couplings [2]), fibrations "melt" temporarily but reform with increased entropy, driving the arrow of time. Globally, entropy cycles through self-similar universe branches (potentially 4 at a time in 4D volume), but locally increases, satisfying the second law without added axioms.

6 Numerical Methodology and Results (Extended)

To numerically test the topological protection in the Hopfion model, we implemented a GPU-accelerated simulation using CUDA on an RTX 2060. The methodology involves relaxing random SU(3)-valued fields on a 4D periodic lattice of size N^4, using gradient flow with complex noise and Gram-Schmidt projection to enforce the manifold. The energy functional is

$$E = \sum (3 - \mathrm{Re}\,\mathrm{Tr}(U^\dagger U_\mu)) + \alpha[(3 - \mathrm{Re}\,\mathrm{Tr}(U^\dagger U_\mu))^2/3],$$

with α as the coupling (ALPHA).

Simulations were run for N from 4 to 64, with 1000 steps and step_size=0.001. Results for ALPHA=1 show stable residuals 6.17-6.42 for N=8-48, dropping to 3.92 at N=64, indicating leakage at large volumes. For ALPHA=10, stability extends to N=52 (34.5-34.9 plateau), with decay at N=56+ (28.85 to 19.93). These non-zero residuals confirm protection, with a critical scale N=32-36 for peak coherence.

6.1 Effective Model Simulations Using TenPy

To further validate the model's predictions in an effective low-dimensional setting, we simulated a quantum ladder model encoding aspects of the Hopf fibration using the Tensor Network Python (TenPy) library. This setup models a spin-1/2 ladder lattice with periodic fields derived from a 4π-parameterized curve, incorporating Schrödinger-Korobochka methods [2] for field scaling. The simulations use DMRG for ground state computation followed by single-site TDVP for time evolution over 40 frames, tracking the variance and mean of the magnetization projection $\langle \mathbf{m} \cdot \mathbf{n} \rangle$, where $\mathbf{n}$ is the topological director field.
Three variants were tested:
- **viviani_ladderCHKSP.py** (baseline Schrödinger method with viviani normals, L=96 per chain, total sites=192): Variance = 3.144869e-02, Mean = -5.091209e-04, Final Energy = -12145.4199908806.:
- **VivKoro4FM.py** (Tested with Korobochka's method at factor=8, L=192 per chain, total sites=384): Variance = 3.764769e-02, Mean = 6.153754e-05, Final Energy = -24356.9572633022.:
- **VivKoro7FM.py** (Tested with Korobochka's method at factor=7, L=192 per chain, total sites=384): Variance = 2.113268e-02, Mean = 4.571159e-05, Final Energy = -24358.8818876758.:
Korobochka's method with factor=7 yields the lowest variance (44% reduction vs. factor=4, 33% vs. baseline), indicating improved topological stability consistent with the model's use of fine-structure-constant-derived scaling ($\alpha \approx 1/137.036$). Energies scale approximately with system size, with the factor=7 variant achieving a slightly lower (more stable) ground state.

Partial variances from the time evolution logs show convergence trends, with the factor=7 run stabilizing faster and at lower values. For instance, in VivKoro7FM.py, partial variances hover around 2.0-2.1e-02 after frame 10, while the baseline baseline reaches higher values (3.1-3.6e-02). This supports the emergence of persistent zero-point motion and topological protection against decay.

These effective 1D+1 simulations serve as analogs for the 4D Hopfion, demonstrating conserved charge-like behavior in the projection variance, which remains non-zero and bounded, mirroring the non-trivial Hopf invariant in higher dimensions.

6.2 Classical Spin Chain Simulations Using CUDA

To probe the scaling of zero-point fluctuations in large systems, we developed a GPU-accelerated classical spin chain simulation in CUDA, modeling the Viviani field-driven dynamics as a proxy for Hopfion threads. The code relaxes and evolves ensembles of spin chains using Langevin dynamics (torque + noise), computing ¡m·n¿ variance over time steps.

Results for various N:

N	Var Low Noise	Var High Noise
4	0.0787	0.0836
64	0.00521	0.00494
192	0.00196	0.00185
4096	9.06e-05	9.00e-05
500000	7.68e-07	6.67e-07

Table 1: Variance of ¡m·n¿ vs. chain length N, showing 1/N scaling but persistent non-zero residuals.

The variances follow a power-law decay $\sim 1/N$, but remain non-zero even at N=500,000, supporting the model's prediction of irreducible topological motion. High noise (dissipation) reduces var slightly without zeroing it, indicating robustness.

6.3 Pinning Simulations for Unwinding Entanglement

In addition we also tested unwinding entanglement wound by hopfions, and found that certain pinnings could peek inside the normally invisible zero energy threads.

N	h_pin	S_half	mean_mn	var_mn	energy	timestamp
12	2.0	1.160042	0.011360	0.000274	-772.808930	2025-12-14T23:02:19.716082
32	2.0	1.498501	0.000867	1.553e-07	-2040.473319	2025-12-15T00:04:17.121784
40	2.0	1.573326	0.000802	6.521e-08	-2549.115010	2025-12-15T02:03:06.148861
32	5.0	1.498501	0.000868	1.561e-07	-2040.473330	2025-12-15T03:02:05.548007
40	5.0	1.573326	0.000803	6.524e-08	-2549.115026	2025-12-15T04:59:19.859044

Table 2: Results from pinning simulations showing entanglement entropy (S_half), mean and variance of $\langle \mathbf{m} \cdot \mathbf{n} \rangle$, and ground state energy for different chain lengths N and pinning strengths h_pin.

References

[1] B. Kerr. The Geometry of Semantics: Universal Cognitive Geometry and the Convergence at Rank k=32. *Substack*, 2025.

[2] Korobochka. Relativistic Soliton Mechanics: Quantum mechanics as the unique low-energy limit of non-Linear electromagnetics under Lorentz invariance: the derivation of Planck's relation, De Broglie's relation, the London equation, the Klein Gordon equation and Schrödinger's equation from a solitonic field ontology [DRAFT]. December 17, 2025. Available at: `https://x.com/cirnosad/status/2001231538495861127`.

A repeatedly noted strong stabilization at N32 might also reveal why consciousness seems to arise that complexity as some believe [1].